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Comprehensive analysis of BSY as a biomass for potential energy resource recovery

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Abstract

Beer is one of the most consumed beverages in the globe reaching an average consumption of 23L per person per year. This makes brewing industry one of the leading economic contributors to most countries. Large amount of organic waste that pollute the environment are produced in beer making processes. The brewing by-products may reach 3%–30% of the volume of beer produced. The management and disposal of the by-products represent a significant cost for the brewery industry and a great concern for a sustainable brewery operation. There is need to resolve the waste management and environmental issues associated with this process using innovative, symbiosis and circular economy approach. Bio-circular models increase the need for resource conservation and waste beneficiation. This study explored the use of brewery spent yeast for energy production under anaerobic digestion and to evaluate its suitability as biomass for energy resource recovery with the potential to shift the brewery sector from the linear to the circular economy practice. Waste quantification, characterisation, and waste to energy conversion through biomethane potential test with AMPTS 11 set-up were investigated. It was observed that the brewery spent yeast had good proximate and ultimate results with the optimum biomethane yield obtained at 304,75 Nml. It was established that the brewery spent yeast offered a high prospect as a biomass and for the future energy mix with potential to contribution to sustainable circular economy business model.

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Keywords: Resource efficiency; Circular economy; Anaerobic digestion; Energy recovery; Brewery spent yeast

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Nomenclature

AD	Anaerobic Digestion
AMPTS	Automatic Methane Potential Test System
BMP	Biochemical Methane Potential
CHNS	Carbon Hydrogen Nitrogen Sulphur
PEETS	Process Energy Environmental Technology Station
HRT	Hydraulic Retention Time
WWS	Wastewater sludge
BSY	Brewery spent yeast
VS	Volatile solids
TS	Total solids
Mc	Moisture Content
Cv	Calorific Value

1. Introduction

The effects of rising fuel costs and the pressing need to reduce earth's carbon footprint have foregrounded the importance and emergence of renewable energy sources in recent years. The latter are highly recommended in food and Beverage sector plants to improve efficiency and promote circular economy ideologies. The most explored options in the processing and management of an organic-rich waste are its ability to produce biogas and its influence on the overall anaerobic digestion process. The beer production generates spent grain (SG) and spent yeast (SY) with high energy potential i.e., SY from the fermentation and SG from smashed barley grains. Saccharomyces yeast biomass is the subsequent major by-product (after brewer spent grain) from the brewing industry. It can be of great value as a raw material with different uses such as animal feed. However, it is still underused [1]. The yeast that is used by brewers undergoes several generations (usually 4 to 6 times) and taken from one fermentation to start the next. It has received little attention as a profitable commodity, and its disposal is an environmental problem. Several attempts have been made to use Saccharomyces yeast biomass in biotechnological processes, including fermentative processes for the production of value-added compounds such as ethanol; as a substrate for microorganisms cultivation, or raw material for extraction of compounds [1]. Considering the increasing interest on bioenergy production and the high content of organic matter that surplus yeast contains, its anaerobic digestion for biogas production becomes an alternative.

Traditionally, spent yeast is dried and sold as a nutritious substrate to the food-processing industry. Zupančič et al. [2] conducted showed that such processing is very energy demanding due to the large amount of natural gas required for the drying, and with ever-increasing energy prices such a procedure is becoming more expensive economically constraining. Waste yeast is high in organic solids' content and can be used as an additional substrate to produce biogas and in return save the natural gas that is used during the brewing process. This research paper looks at the possibilities of using waste yeast as an energy substrate to increase biogas production in brewery-wastewater treatment.

Pickup and Langkjaer [3] reviewed the yeast above and found that these types of yeast have several properties, which make them exceptional for industrial use and particularly the brewing industry. These properties include fast growth, good ability to produce ethanol and tolerance for several environmental stress, such as high ethanol concentration and low oxygen levels. Spent yeast referred to as spent/dead yeast or trub is a residue produced during the brewery process, which presents high contents of organic matter. Oliveira, et al. [4] investigated the biochemical methane potential of these by-products by performing batch anaerobic biodegradability assays evaluating single substrates and a mixture of SY: SG (1:9, weight), in order to simulate the relative proportion generated in breweries. The study revealed that the SY reached the highest BMP [(515 $\pm$ 4) L kg-1]. Considering the total amount of by-product available, the SY proved to be more rewarding in terms of volume of methane produced thus evidencing its potential for energy generation, with the potential of offering 80% of the brewer's energy needs for heating. He further noted that there are two problems that can be identified with the anaerobic digestion of the brewery by-products: first, the high cellulose content (up to 25%) of the spent grain [5] and second, (2) the high content of proteins in both substrates.

The anaerobic digestion process enables the generation of biogas that can be used as a clean alternative source of energy. This property is because the biogas generated by AD has a high methane content, which in turn has a high heating value. This basically means that the combustibility of methane in the presence of oxygen will result in flame propagation [6]. Anaerobic digestion is dependent on numerous factors, which have an impact on the quality of biogas produced. The design, stability, and the performance of biodigesters also depend on these factors. First, the substantial fraction of the material can be broken down further into volatile solids (biodegradable), and non-volatile [4]. The distinction between the water contents and the solid contents (dry matter) of the feedstock is essential in determining the quality of the feedstock and therefore, the performance of the AD [7]. The larger the percentage of VS that is available, the more methane is produced [7]. The second factor is the organic loading rate, which is the amount of digestible material supplied into the digester each day in kg or COD (Chemical Oxygen Demand) per m^3 [8]. Estevez et al. [8] explored this effect by comparing two different organic loading rates with their respective biogas production. According to Comino et al. [9] during the co-digestion of crops silage and manure, increasing the organic loading rate from 4.45 to 5.15 g VS/L/d resulted in a 5% increase in methane output. Third, during the early phases of anaerobic digestion (i.e. hydrolysis, acidogenesis and acetogenesis), the pH level's instability has a negative impact on the biogas yield [10]. During these early stages, the pH drops due to the production of organic acids. Because of the synthesis of ammonia, the pH of the substrate may slightly increase once it reaches the methanogenesis stage [10]. Below pH 6, CH4-forming bacteria are inhibited, and the anaerobic digestion process is disturbed. Because methanogenesis is the yield-limiting process, it is important to keep pH near to neutral during operation. Fourth, there is the C/N ratio, which is a classic AD metric that is been studied extensively in a number of studies [11]. The C/N ratio indicates the amount of organic carbon (as measured by COD) and nitrogen (as measured by N) contained in the feedstock. Individual CH4 yields and CH4 content change in lockstep with the C/N ratio [11]. The optimal C/N ratio has been determined to be in the range of 20 to 30. Finally, VFAs produced during AD are significant intermediate products that are linked to AD imbalance. Failures are generally caused by an imbalance among acidogenic, acetogenic, and methanogenic organisms when VFA concentrations are high [12]. The concentration of VFAs in an anaerobic digester was found to be limited to 13000 mg/L for consistent functioning [12]. Additionally, higher VFA generation results in less effective COD elimination [12].

The composition of the substrate is a determining factor in determining the biomethane potential of substrates either mono or co-digested. It may also be assessed whether a given substrate is suitable for energy resource recovery by looking at the moisture content (MC), volatile solids (VS), total solids (TS), Carbon to Nitrogen ratio (C/N), and carbon, hydrogen, nitrogen, and Sulphur content (CHNS). This activity has been associated to shortage of suitable substrates for biogas production and as means of waste management addressing environmental and energy related issues. This study presents a comprehensive study of brewery spent yeast (BSY) to determine its potential as biomass for potential energy resource recovery.

2. Material and methods

The study conducted a comprehensive analytic evaluation to determine the methanogenic potential of brewery spent yeast (BSY) as the biomass for potential energy resource recovery. Fig. 1 present the procedure carried out for waste quantification, characterization, waste to energy conversion using anaerobic digestion technology. The organic samples underwent a chemical process aimed at producing biogas using the biomethane potential test technique.

2.1. Equipments

Electronic weighing machine, oven, muffle furnace, desiccator, evaporating dish, calorific value analyser, digital weighing machine, element analyser, digital pH meter, vials were used for waste measurement and waste characterisation of the brewery spent yeast substrate. Further to this, DRB200 digester and DR1900 analyser from Hach Company was used in accordance with the manufacturer's manual attached at purchase for Chemical oxygen Demand.

Thermo Scientific Flash 2000 Organic Element Analyser equipment was used to conduct elemental analysis CHNH to determine the C/N ratio. Calorific value analyser equipment was used to determine the Calorific value of the substrates under investigation.

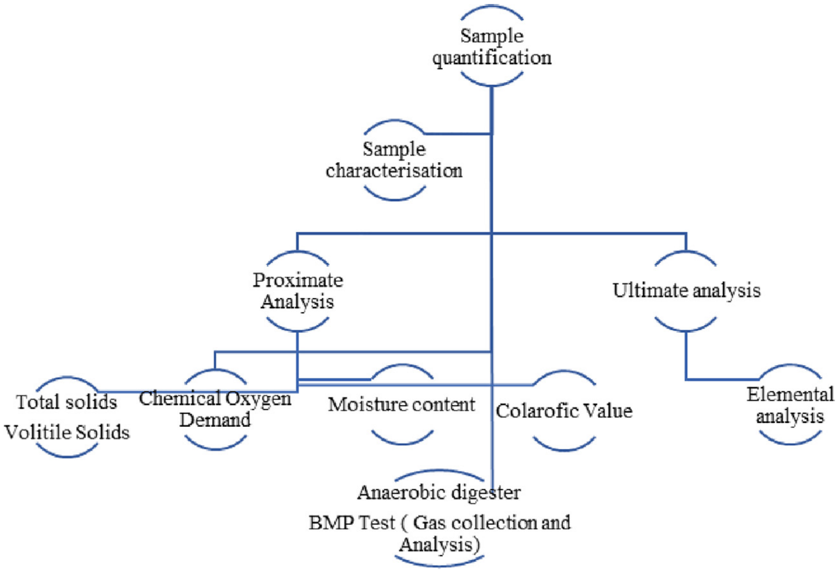

Fig. 1. Flowchart for waste quantification, characterisation, and conversion of waste to energy.

3. Methods

3.1. Substrate quantification and characterisation

The study was limited to just one substrate, which is the brewery spent yeast (BSY). The brewery spent yeast used in this study was quantified at a Brewery plant in Alberton, Gauteng province, South Africa. This involved collection and measurement of substrates. The brewery spent yeast was collected using a 20l bucket with a lid, a 4th generation spent yeast was used was stored in a fridge at 4 °C until further processing such a characterisation and for feeding in the BMP digesters was required.

Characterisation was done to ascertain the composition of the substrate under investigation. The analysis included the physical and chemical composition with regards to chemical oxygen demand, proximate analysis which entailed volatile solids, total solids and moisture content test, and ultimate analysis (elemental analysis) for carbon, nitrogen, hydrogen, and sulphur (CNHS). The characterisation was conducted in accordance with the standard methods developed by APHA in 1995 [13].

3.1.1. Biomethane potential test experimental procedure

Methanogenic potential was determined in digester bottles with 400mL of useful volume using the BMP11 set up. All the samples were loaded into the digester and initial pH was measured, was set at 7.0. Methane production was determined by liquid displacement using a NaOH solution to absorb carbon dioxide. Analyses were performed in duplicates; pH was also measured after the digestion process. When preparing the experiment, the inoculum to substrate ratio was chosen based on the *VS* of the sample. The inoculum used was from the previous set-up digested for *14 days* to expel biogas and supply with microbes.

4. Results and discussions

4.1. Characterisation of substrates

4.1.1. Proximate and ultimate analysis

The proximate and elemental compositions of the brewery spent yeast was investigated. The characterisation of the substrate was done by analysis of the moisture content (MC), volatile solids (VS), total solids (TS) carbon to nitrogen ratio (C/N) and carbon, hydrogen, nitrogen, and sulphur (CHNS). Further to this chemical oxygen demand was performed on the substrate before digestion. Table 1 shows the characterisation results of the Brewery spent yeast.

Table 1. Characterisation results for brewery spent yeast.

Substrate	C	H	N	S	MC%	VS%	TS%	C/N ratio	COD (mg/l)
Brewery spent yeast	43.7	6.73	1.65	0.03	86.23	12.65	13.76	26.48	154616

The characterisation and the composition of the substrate was a determining factor in determining the biomethane potential of substrates. Also, it could determine whether a particular substrate was suitable substrate as an energy resource recovery. The MC for brewery spent yeast was found to be 86.23%. This indicated that the brewery spent yeast had a good MC for anaerobic digestion. Studies done by Mora-Naranjo [14] showed that the moisture content contained in the substrate plays a crucial role in biogas production because the nutrients and the microorganisms must dissolve in the water phase before they can be assimilated, and it supports bacterial movement and helps substrate and product diffusion through the porous medium to bacterial sites. The brewery spent yeast had a VS% of 12.65%, which meant that the substrate was rich in organic solid content that can be converted to biogas. The higher the VS%, the higher the organic content, which is favourable to produce biomethane. TS is used to describes dry matters of a substrate. A study conducted by E. K. Orhorhoro [15] has shown that the increase of TS %, decreases the biomethane potential of the substrate. This is due to the drop in water volume which consequently reduce the level of microbial activity, thus, results in a low biogas yield. In this case BYS had the low TS% which then explain the High moisture content. Within the anaerobic digestion process, the C/N ratio is a major determinant of the organism's stability. Table 1 demonstrates that BSY has a C/N ratio of 26.3 percent, which is excellent for anaerobic digestion and is within the ideal range (20 to 30). The C/N ratio is a common measure that has been studied extensively in several AD investigations [11]. The C/N ratio denotes the amount of organic carbon (as measured by COD) and nitrogen (as measured by N) contained in the feedstock. The C/N ratio is constantly followed by variations in certain CH4 yields and CH4 content [11]. Because anaerobic microorganisms require a sufficient amount of nitrogen to develop, a low nitrogen level would hinder AD. Simultaneously, organic carbon is regarded as the sole source of anaerobic action [11]. A low C/N ratio causes an increase in pH. A high C/N ratio, on the other hand, results in rapid nitrogen conversion and minimal biogas generation [11]. It has been shown that the optimal C/N ratio is in the range of 20 to 30, with a typical value of 25. In this case, the C/N ratio was on the range of 20 to 30 with 26.48.

4.1.2. Calorific value (CV) of substrates

The Calorific value (CV) was determined using E2K calorimeter. The calibration of the calorimeter was verified using Benzoic acid (Standard value of 26.5 MJ/Kg). Before combustion of the sample, the calorimeter vessel was filled with oxygen at a maximum pressure of 2000 kPa. The BSY samples were prepared and assessed with each sample weighing a total of 0.5 g. The result of the calorific value of the sample is shown in Fig. 2

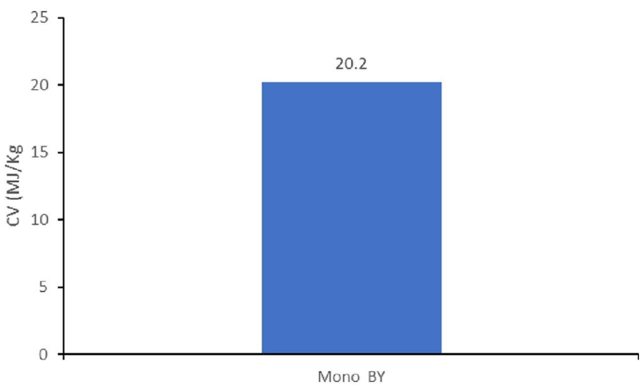

Fig. 2. Calorific value of substrates.

The quantity of energy generated in the form of heat from the combustion of a sample using an oxygen bomb calorimeter was known as the calorific value, also known as the higher heating value (HHV). Brewery spent yeast had a high calorific value of 20.2. Calorific value is directly proportional to the volatile solids of the substrate, the higher volatile solid the higher the Calorific value.

4.1.3. Chemical oxygen demand (COD) value of substrates

Chemical oxygen demand was done on the brewery spent yeast as a measure of the susceptibility to oxidation of the organic and inorganic materials present in the substrate. Table 2 shows results for COD, VFA and Ph over the duration of the experiment.

Table 2. Results for COD, VFA and Ph over the duration of the experiment.

Substrate	Ph range		VFA(Acetic acid) mg/l		VFA(Butyric acid) mg/l		COD (mg/l)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Effluent	Effluent
Brewery spent yeast	6.60	6.65	576	nd	2600	nd	154616	12 369

Nd: not detectable.

The variability of the pH level during anaerobic digestion negatively influences the biogas yield especially during the early stages of the anaerobic digestion such hydrolysis, acidogenesis and acetogenesis [10]. Table 2 shows that the brewery spent yeast was working at the ideal pH range of 6.2 to 7.5. Methanogenic bacteria are more pH sensitive and require a pH range of 6.5 to 7.8. The Volatile Fatty Acids (VFAs) created during anaerobic digestion are important intermediate product and relates to the imbalance of the AD system. High VFA concentration was reported to cause failures due to an imbalance among acidogenic, acetogenic and methanogenic organisms [12]. The brewery spent yeast had the VFAs concentration of 2600 mg/l which is within the range for stable performance in an anaerobic digester which was reported at 13000 mg/L [12] and a range of 2000–4500 mg/L and confirms that bacterial activity had occurred and broken down the available acids to form biogas. This is also evident in the COD concentration of the substrates. A decrease in COD in the brewery spent yeast was observed, a COD removal of 92% in brewery spent yeast was noted. The chemical oxygen demand was measured using the Hach DR 3900 and DRB200 digital analyser. The decrease in the available oxygen in the effluent confirms the breakdown of organics material to biogas and the AD efficiency which agrees to the study conducted by Hamawand et al. (2015) [16].

4.1.4. Biomethane potential of BSY

The analysis was experimentally achieved in a laboratory scale using automatic methane potential test system (AMPTS II). In this system biochemical methane potential (BMP) tests were performed to determine the anaerobic biodegradability and optimum methane potential of waste in question. Fig. 3 shows the biomethane production of brewery spent yeast,

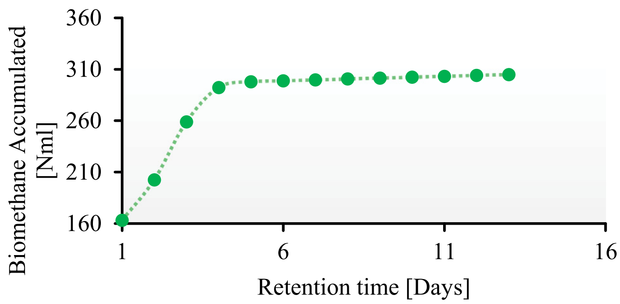

Fig. 3. Anaerobic digestion of brewery spent yeast.

The biomethane potential test was vital in assessing the biomethane production of the respective organic feedstock amid its anaerobic deterioration. Fig. 3 shows the biomethane production from the mono-digestion of the brewery spent yeast substrates. The retention time for substrate digestion to yield biomethane was between 16 to 21 days. In Fig. 3, the biomethane production of brewery spent yeast is presented and shows that the substrate stated producing biomethane from the first day and gradually increasing until the optimum was reached at the value of 304 NmL

CH4/g VS in 13 days and the nutrients were exhausted. The brewery spent yeast produced the high biomethane because of the high VS composition and balance.

5. Conclusion

The brewery spent yeast was analysed in terms of the proximate and ultimate test to address the multidimensional needs of waste beneficiation as well as provide energy security for the brewing industry. This study further analysed the potential of BSY to produced biomethane. The brewery spent yeast had a VS% of 12.65%, which meant that the substrate was rich in organic solid content that can be converted to biogas. The higher the VS%, the higher the organic content, which is favourable to produce biomethane. Further to this has shown good results of C/N ratio 26.48 which was within the expected rage 20–30, calorific value 20.2, and the ability of a COD removal of 92%. This study has further shown that brewery spent yeast can serve as a sustainable substrate towards the production of biomethane and that it has a good potential as biomass for energy resource recovery.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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